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8' x 4' x 200' ADJUSTABLE RECIRCULATING FLUME

by

D. B. Simons

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TERMINAL REPORT

8' x 4' x 200' ADJUSTABLE RECIRCULATING FLUME

Prepared for National Science Foundation
under Grant 21826

by

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Introduction

Presented herein is a report on the design and construction of the large recirculating flume partially financed by N.S.F. G-21826.

The report covers the period from January 1, 1963 to January 1965 inclusive.

The personnel associated with the project include:

A. R. Chamberlain - Vice President for Administration.

D. B. Simons - Professor and Associate Dean for Research and Chief of the Civil Engineering Department.

S. S. Karaki - Research Engineer and Associate Chief of the Civil Engineering Department.

J. N. Nath - Assistant Professor of Civil Engineering.

Fred Watts - Junior Civil Engineer.

George Alger - Research Assistant.

Khalid S. Al-Shaikh Ali - Research Assistant.

P. M. Jog - Research Assistant.

Ralph Asmus - C.S.U. Shop Foreman.

Valuable assistance was also given by H. P. Guy and E.V. Richardson of the U.S. Geological Survey.

This large adjustable recirculating flume has been developed and constructed primarily for the study of bed forms, resistance to flow and sediment transport in alluvial channels and the study of rigid boundary open channel flow. Also, the flume will be used as a towing tank and wave basin.

With this length of flume and the special tailgate features it is anticipated that uniform flow conditions will be easily obtainable in the middle 150 feet of the flume. The large size of the flume makes possible the duplication of field problems under laboratory conditions. Despite the size of the unit it has been so designed that it retains the operating advantages and flexibility of smaller standard flumes.

N.S.F. G-21826 provided $34,400 of the estimated $110,000 total cost of the flume.

Construction of the Flume

The hydraulic design was made by E. V. Richardson, S. S. Karaki and D. B. Simons. Professor J. H. Nath carried out the structural design and prepared the drawings for the flume, which were approved by A. R. Chamberlain, S. S. Karaki and D. B. Simons. Construction of the flume was started on January 1, 1963 and was completed by February, 1965.

The 3 span continuous steel vierendeel truss and the flume were fabricated in place under the supervision of shop foreman R. V. Asmus and S. S. Karaki, Research Engineer and Associate Chief of the Civil Engineering Department.

A side elevation of the flume and a few structural details such as built-in adjustable supports for longitudinal and transverse leveling of the floor and plumbing the walls, the joint sealing arrangement and carriage support equipment, are shown in Figure 1. A general view of the flume is shown in the background of Figure 2. The interior of the flume, looking downstream, is shown in Figure 3. A set of 3 multivane diffusers designed for suitable entry of fluid from each of the three recirculating pipes can be seen in Figure 4. The depth and backwater in the flume can be controlled precisely by means of adjustable fingers provided near the tailgate as shown in Figure 5. The positive gate shut off to convert the flume to a towing or wave basin and to help control outflow in case of a power failure is shown in Figure 6. Figures 7 and 8 show the jacking units. A working and observation platform is provided all along the flume, a portion of which, near the head-box, is shown in Figure 9. The outfall sump is located between the pump pit and the end of the flume. The outfall sump is designed to avoid sediment storage and to allow air entrained by the jet of water to escape from the water before entering the return pipes and being pumped back to the headbox of the flume. Figure 10 shows the sump during construction and the piping connecting the sump and the pumps. Three recirculating pumps capable of carrying a maximum discharge of 100 cfs are installed in the pit at the end of the flume as shown in Figure 11.

Main Features of the Flume:

1. An adjustable slope 0 percent to 3 percent which can be varied with the synchronous motor-driven jacking system.
2. Discharge capacity ranging from 0 to 100 cfs given by three pumps, a 15 cfs centrifugal pump with variable speed motor, a 35 cfs centrifugal pump and a 50 cfs axial flow pump.
3. Live-load deflections less than 0.01 ft for any span under a water load of 3'-6" depth of water in the flume.
4. Fully automatic synchronized-electromechanical jacking units capable of maintaining true centerline slope of flume to an accuracy of ± 1/16" per 200 ft, see Figures 7 and 8.
5. An experimental reach 70 ft long, in the middle of the flume, with transparent lucite plastic walls for observation and photography.
6. An instrument carriage with rack and pinion gear drive for positioning the instruments laterally, vertically and longitudinally. The carriage will be used for towing purposes and its longitudinal speed can be precisely controlled between 0 and 10 fps.

PROPOSED EXPERIMENTS

With greater world-wide utilization of water resources the importance of knowledge of river mechanics, channel stability, design of stable channels, sedimentology and fluvial morphology are of importance for technical and economic reasons. A greater effort should be devoted to these significant areas which, for example, bear on problems of navigation, flood control, flood protection, water supply and water quality. Such studies would minimize the problem of extrapolating questionable answers to important problems from empirical and semi-empirical relations.

The large flume has been designed to facilitate basic research pertinent to further development of the theory of the mechanics of flow in alluvial and rigid channels by graduate students and faculty. A proposal titled "Stable

Alluvial Channels," No. CEP64HWS-DBS45 has been proposed to the National Science Foundation. If funded the study will utilize this facility. It is proposed to study both analytically and experimentally:

1. the shear distribution on the boundary of channels with different cross-sections,
2. the ultimate stable cross-section of alluvial channels under different hydraulic conditions and sediment without sediment inflow based on the variation of shear distribution along the boundary,
3. the effects of sediment load, seepage force and flood plain material on the ultimate stable channel cross-section,
4. the application of the results obtained from laboratory studies to explain the fluvial morphology of rivers,

Other priority studies which are planned for the future some of which were suggested as priority items by the stable channel committee (D. B. Simons, Chairman) at the ASCE Irrigation and Drainage Conference, March 1964 follow:

I. Alluvial Channels

A. Bed Forms in Alluvial Channels and Their Relation to Roughness and Resistance to Flow--The alluvial channel is unique in that if the bed material is mobile with flow, bed forms are generated which are related to the characteristics of the bed material, the geometry of the channel and the flow. Various bed forms which normally occur in alluvial streams have been studied in some detail. In general, we can estimate the resistance factor if we know the form of the bed roughness. Nevertheless, many facets of this important problem remain unanswered. It is essential to more clearly define the forms of bed roughness which occur in alluvial channels. It is necessary to determine specifically when certain bed forms will and will not form. It is equally important to be able to predict the form of bed roughness one can anticipate under specified design conditions. Without this ability a refined design of stable channels can not be achieved. Another facet of this problem which is only generally understood is why the bed forms change as flow conditions are varied. Hence, we should study the physical reasons behind the development of the various bed forms, and why under certain circumstances bed forms such as ripples and dunes vanish altogether in favor of a plane or flat bed. It is also essential to study the larger, alternating bars which develop and move in alluvial rivers and canals. In some instances these bars are of such small amplitude it is difficult to identify them. Under other circumstances these bars may develop to such an amplitude that they approach the general water surface deflecting the flow back and forth in a meandering pattern around them. The formation, migration and eradication of these large bars significantly affect channel stability, sediment transport, sorting of the bed material and resistance to flow, and consequently deserve detailed study. Referring to channels whose boundaries are of gravel, cobble or rock, the most common form of bed roughness recognized is that associated with the individual grains (grain roughness). Field studies have indicated that under favorable circumstances even these coarse materials can be molded into large bars similar in shape to dunes. These large bars may affect the resistance to flow in the channels, and at low flows may significantly deflect the main stream in such a manner as to affect channel stability and should be studied.

Bed forms and their relation to roughness and resistance to flow have been investigated by many leading laboratories. In their studies, the development of different bed forms was probably hindered by the shallow water depth of less than one foot. In the new flume, a maximum water depth of three to threece and one-half feet is available.

B. Sediment Discharge Equations--Many concepts and theories have been developed to estimate the magnitude and distribution of the suspended sediment load and bed load. Unfortunately, none of the available theories can provide a satisfactory solution to all flow conditions. Two of the main obstacles are the unpredicability of vertical suspended load distribution and the undefined relationship between the bed load and the suspended load. Studies by Vanoni, Brooks and Chien indicated that the von Karmon's "k" value varied with the suspended load concentration. With large flow depth available in this new flume, studies should be made in this area to further improve existing concepts. The relative movement of grains of different sizes and their distributions should also be studied with the aid of fluorescent tracers and radioactively tagged particles.

C. Turbulence in Open Channels--Thus far it has not been possible to thoroughly investigate the role of turbulence in the mechanics of flow in alluvial channels. With recent advancements in the field of instrumentation, it is now possible to proceed in this field of turbulence using such instruments as the electro-kinetic probe, instruments which utilize the Doppler effect and minute differential pressure transducers specially placed and oriented in probes to measure the turbulence of the flow. Investigations in this area may provide the opportunity to add further refinement to the theories of channel shape, resistance to flow and sediment transport. Coupled with this work the mechanics of diffusion should be studied. Florimetric equipment presently available has made it possible to make rapid advancements in this area.

D. The Effect of Washload on Stable Channels--In general, washload is the fine sediment transported in the stream. Only small quantities of the washload are found in the bed material and its concentration is essentially uniform throughout the flow cross section. Studies thus far indicate that this washload significantly effects channel stability, the development of berms and the apparent viscosity of the water sediment mixture. All facets of these effects deserve further attention as well as other possible properties such as rheological effects of washload.

To illustrate the importance of washload, with concentrations on the order of one-hundred thousand parts per million by weight the apparent viscosity of the water-washload mixture may be ten times as great as water alone. This large increase in apparent viscosity apparently reduces the fall velocity of the bed material making it much more susceptible to transport and consequently it reacts differently with the flow and is molded into different bed forms than prevail for the usual case, perhaps affecting not only resistance to flow but also bed material discharge.

Similarly the effect of variations in sediment concentration and size distribution on the transport capacity of channels and composition of the channel bed material needs study.

E. The Mechanics of the Development of Armor and Utilization of Armoring in Stable Channels Works--Under some circumstances small layers of graded coarse material may be used to stabilize the beds and banks of small channels. In rivers, of moderate depth, coarse material can be used successfully to stabilize the banks. Field observations have clearly demonstrated that a small amount of coarse material in a finer natural material may rapidly develop into an armor as scour and degradation occur. Available information on bed armor, as obtained in field and laboratory studies, should be documented in the technical literature. This natural phenomena can in some situations be of great economic importance and the principles of armoring with coarse materials should be studied.

Also, in armored or coarse bed channels the bed material is static until peak discharges are experienced which exceed preceding peak discharges. These large flows cause transport and rearrangement of the boundary material. The resistance to flow in such channels, changes with reorientation of the bed and bank material, bank stability and transport mechanics under such conditions also deserve attention.

F. Predicting Degradation--This problem is closely related to the one of bed armoring. Small quantities of coarse material scattered within an otherwise generally fine material may further accumulate as degradation occurs developing an effective armor against further degradation. Unfortunately, even with the presence of small quantities of coarse material the development of an effective armor can not always be counted upon. Under certain circumstances of flow the armor developed by degradation may be effective. Under other flow conditions the armor may be destroyed, at least temporarily, allowing additional degradation to occur. It is essential to develop a better method of predicting the extent to which degradation will occur and its stability for various conditions encountered practically in the design and operation of engineering works.

G. Secondary Circulation in Open Channels--The mechanics of secondary circulation should be studied in both straight and curved channels. The secondary circulation should be related to the geometry of the channel which affects the bed configurations, the sediment transport, the water surface profiles particularly in the transverse direction. It has long been recognized that secondary flow around bends in open channels should be studied in detail along with such factors as energy loss, non-uniform flow, and wave activity. So far only limited studies have been conducted and most of these have involved only rigid channels.

H. Non-Uniform Flow--Most of the sediment research studies have dealt with uniform flow problems. Not enough attention was paid to the non-uniform flow problem in alluvial channels. Many canals, drawing water from large rivers, can not be designed to carry all the sediment inflow from rivers at all times. The study of flow conditions in the non-uniform head reach of a canal will provide information on the amount of free board required for the canal to pass a certain discharge, stability and the need for exclusion and/or ejection works. It will also assist with operation problems and the closure of dams.

I. Design in Cohesive Materials --One of the largest voids in design criteria exists where cohesive materials are involved. We do not know which physical and chemical properties predominate in establishing resistance properties, and we do not have instruments or techniques fully developed for performing comprehensive measurements in the laboratory and field. Present and past methods of describing cohesive materials should be carefully reviewed including the plastic index, texture test, chemical compositions and characteristics of the kind determined in a device such as the USBR shear tank. The possibility of developing shear vanes should be pursued. Such research could be carried out in the field on both large and small channels. With the development of a suitable field instrument to measure shear strength, it is also essential to develop an instrument capable of measuring shear stress on the banks of cohesive channels. Concurrently, it is essential to continue the search for parameters or variables which express the resistance to flow of cohesive banks. Perhaps instruments can be designed with which bank resistance can be directly measured.

J. Geologic and Geomorphic Implications--The development of a stable design for a natural stream must involve some consideration of the historical pattern under which the existing channel was created and also consideration of the probable future influences on the channel. The investigations of the geologic and morphologic influences on existing stream systems, and studies in quantitative geomorphology, have been lagging behind until recent years. These aspects are related to stable channels and deserve further attention.

II. Rigid Boundary Channel

A. Drag Forces on Floating and Submerged Bodies

Different types of objects can be propelled with the carriage. The drag force between the object and the fluid can be measured by strain gages because the speed of the carriage is controlled.

B. Dispersion Studies--This flume offers large depths, widths, and lengths for both two-dimensional and three-dimensional dispersion studies.

Different types of tracers can be used. For two-dimensional studies, the bottom of the flume can be artificially roughened to limit the boundary layer growth near the flume walls. With a wave generator, vertical dispersion in waves can also be studied.

C. Two Phase Flow--Fluids of different densitites and/or viscosities can be placed in this flume. Either the top or the bottom fluid can be re-circulated at various speeds to study the instability and drag at the interface. Due to the large flume depth available velocity distribution in the fluids can be measured. The towing carriage can be used to propel objects of various shapes through either of the fluids or along the interface of fluids.

D. Waves--The large flume can find some interesting applications for studying the motion of gravity waves due to flow over obstacles, or waves reflected by structures. The advantage of the large size facility is that waves can be created which are large enough to be unaffected by capillary action, and still have a wave length small compared with the depth of flow.

The large size also makes possible some particularly interesting studies of vibrations of structures existed by waves having a frequency roughly equal to the natural frequency of the structures under investigation. Such problems are difficult to study in a small scale facility because of the difficulties in modeling elastic properties of materials. The structures contemplated could be stationary structures, such as piers, or moving structural elements, such as hydrofoils.

E. Translation Waves--The problem of the difference in flow resistance in steady and unsteady flow and its dependence on wave steepness can be effectively studied in a flume of this magnitude.

The criteria when a gradual wave starts to amplify is also an unsolved unsteady flow problem, both theoretically and experimentally. The large flume with available slope up to 3 percent enables a study to determine the conditions that exist at the time a gradually varied wave (monocular or solitary) begins to amplify, as well as to determine the rate of attenuation or amplifications.

The problem of instability of free surface by wave generation on the free surface for high velocities is another problem worth studying.

F. Resistance to Flow-- False floor panels covered with roughness elements of different form and volume can be easily installed over the flume floor. With proper instrumentation, detailed investigations of the sizes of the zones of separation and their relationship to velocity distribution and to the surface resistance past rough boundaries can be carried out.

APPENDIX

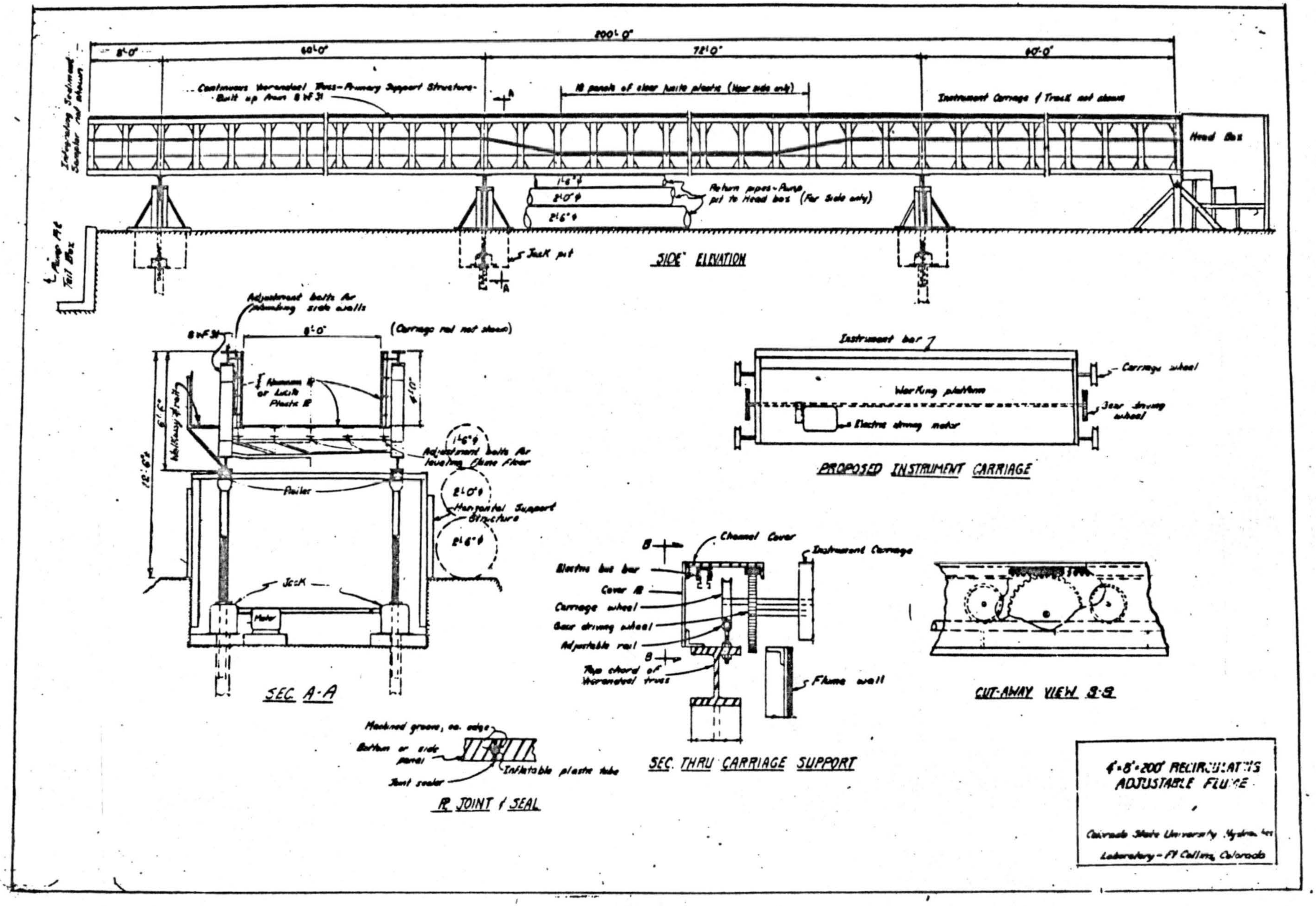

Fig. 1. Schematic drawing of large flume.

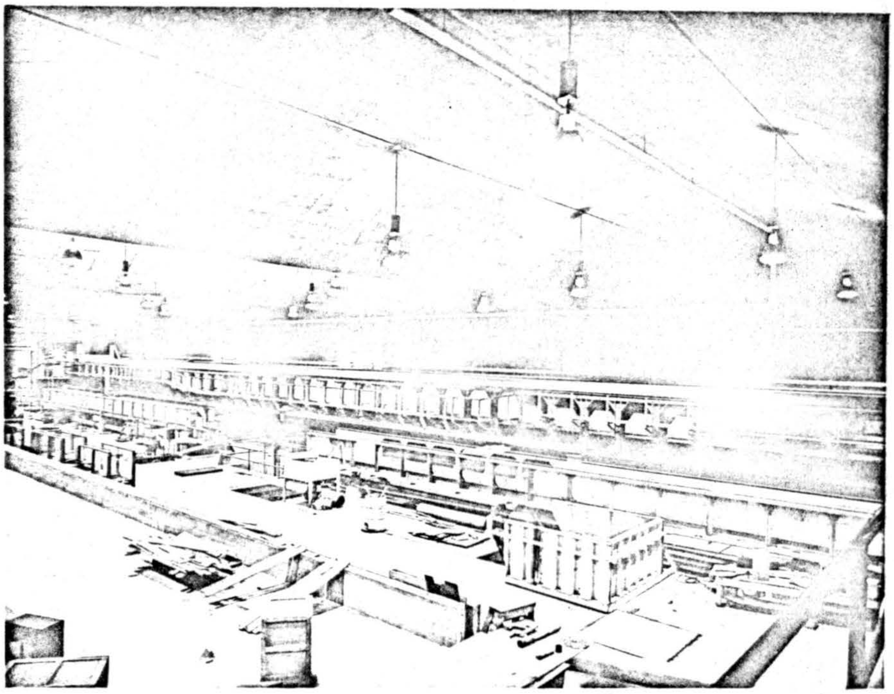

Fig. 2. A general view of the flume occupying nearly three-fourths of the laboratory's entire length. Flow is from right to left.

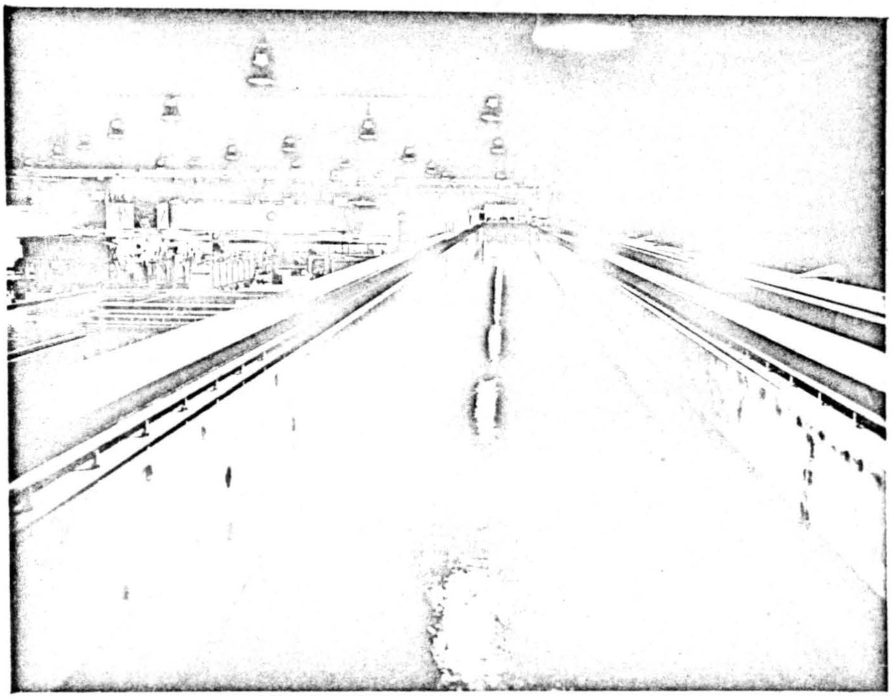

Fig. 3. Interior view of the flume (8 ft wide) looking downstream toward the tail gate.

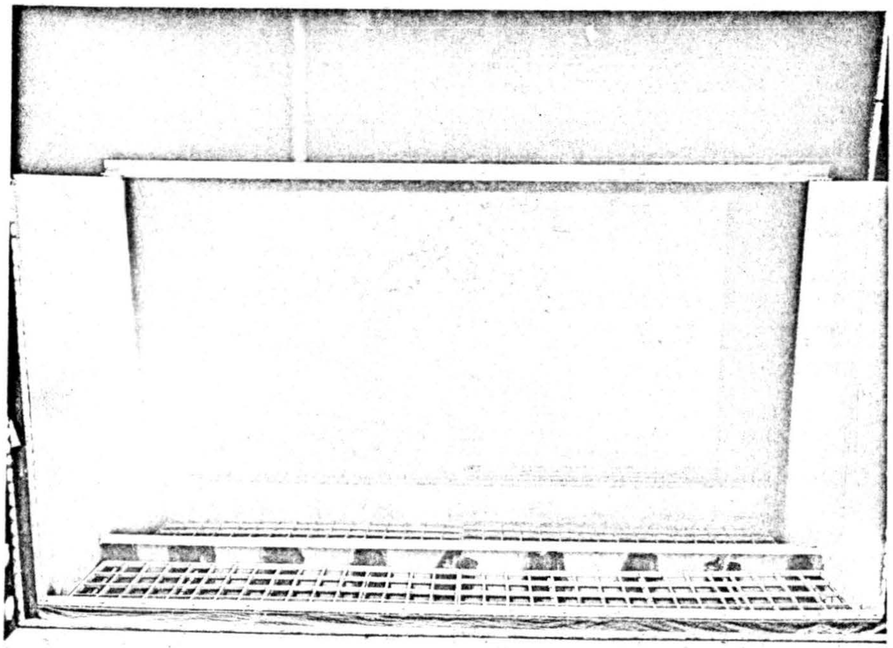

Fig. 4. The flume headbox - designed and checked by modeling - includes three multi-vane diffusers--one for each pump.

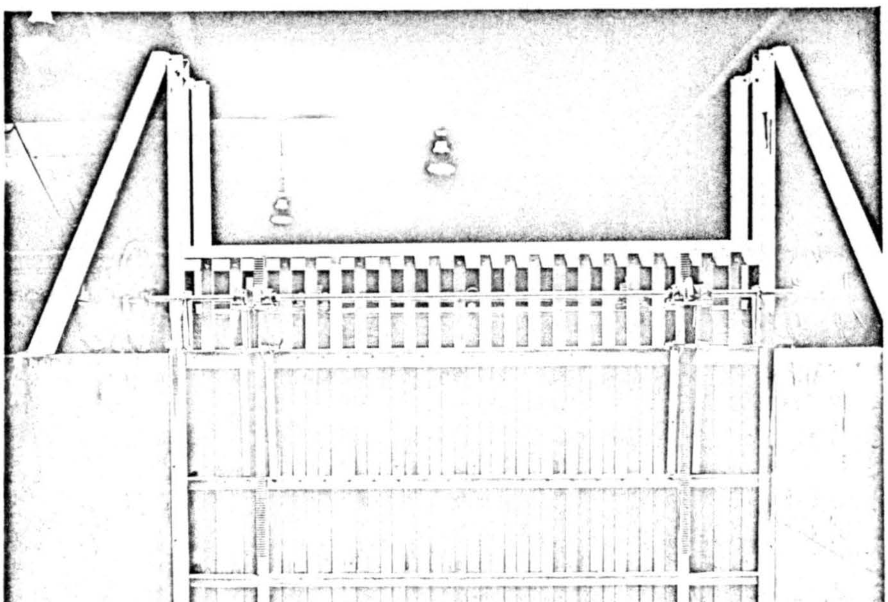

Fig. 5. Adjustable fingers at the end of the flume to control depth and backwater in the flume.

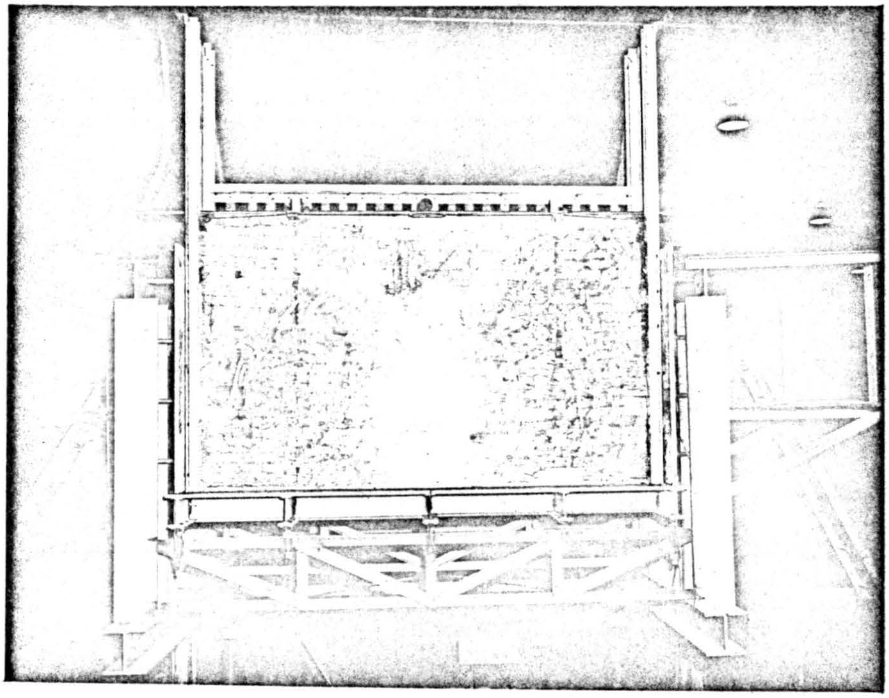

Fig. 6. Positive shut off and control tailgate of the flume looking from outside at the outfall end of the flume.

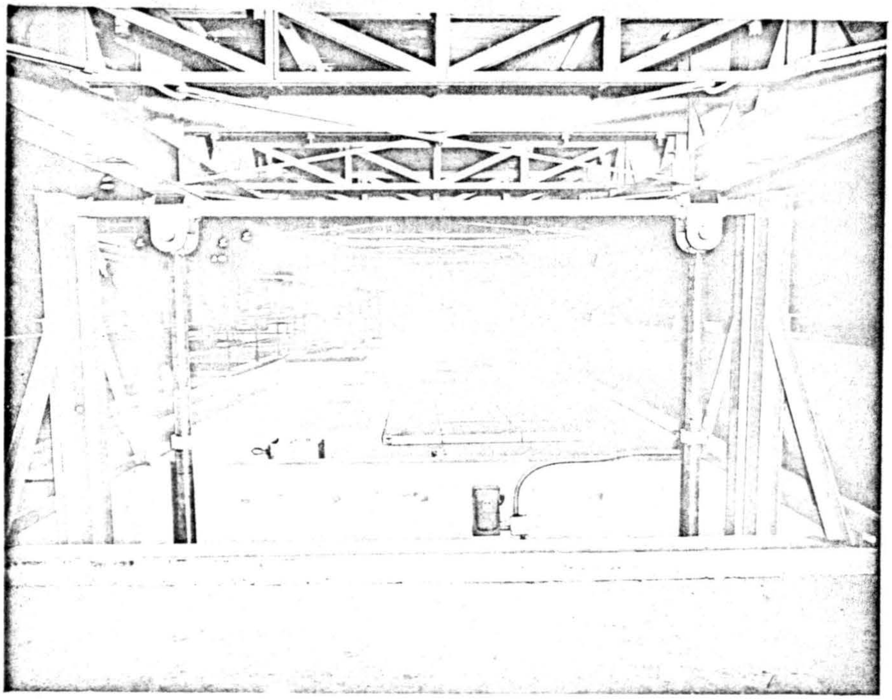

Fig. 7. A pair of one of the three automatic jacking units supporting the flume.

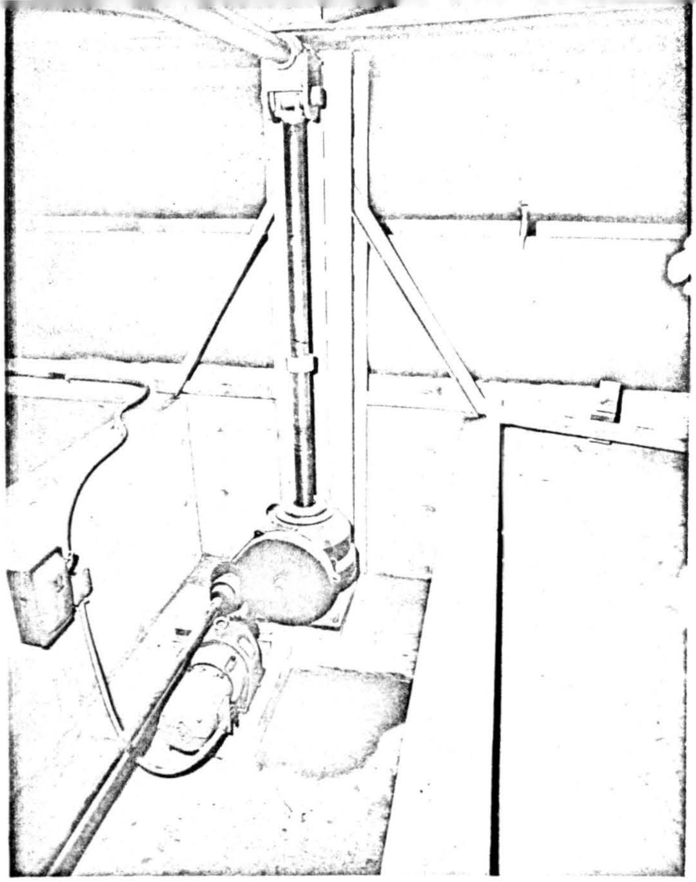

Fig. 8. A close-up of the jacking unit - synchronized electro-mechanical equipment.

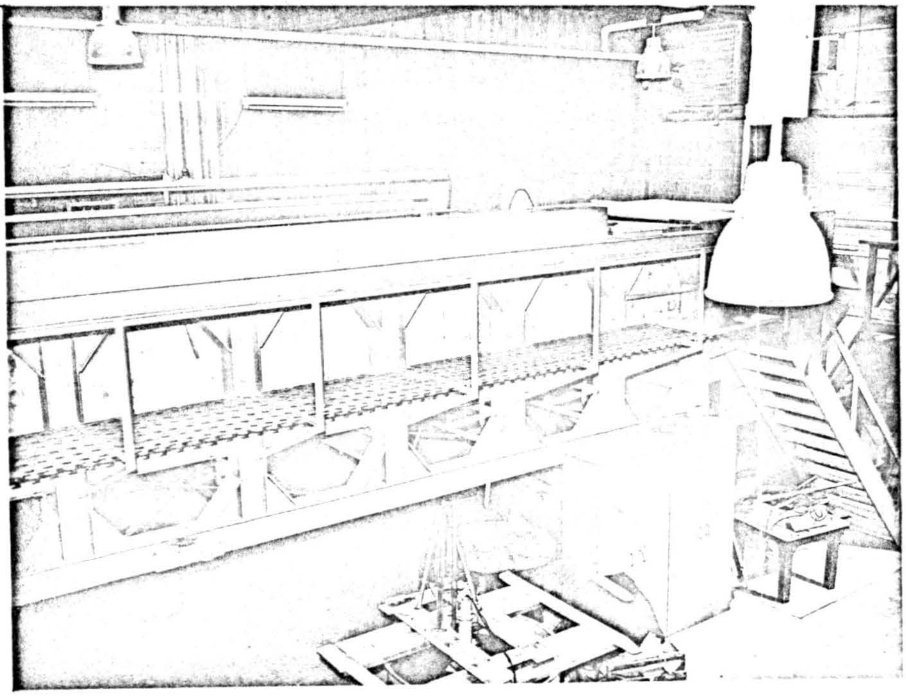

Fig. 9. A portion of the flume near the headbox showing the details of the working and observation platform attached to the girder.

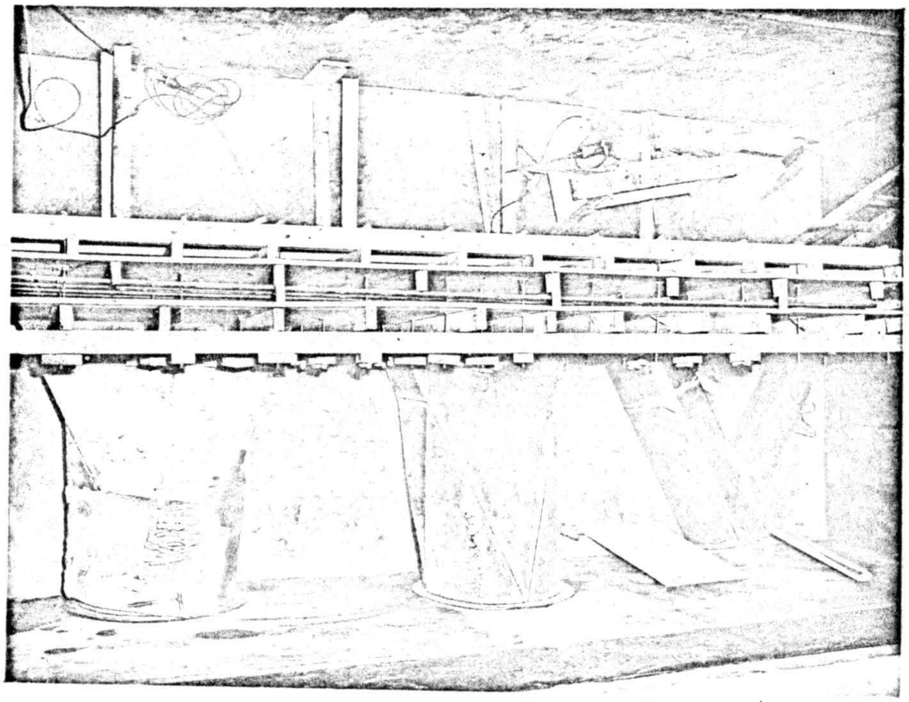

Fig. 10. Plan view of sump at the end of flume.

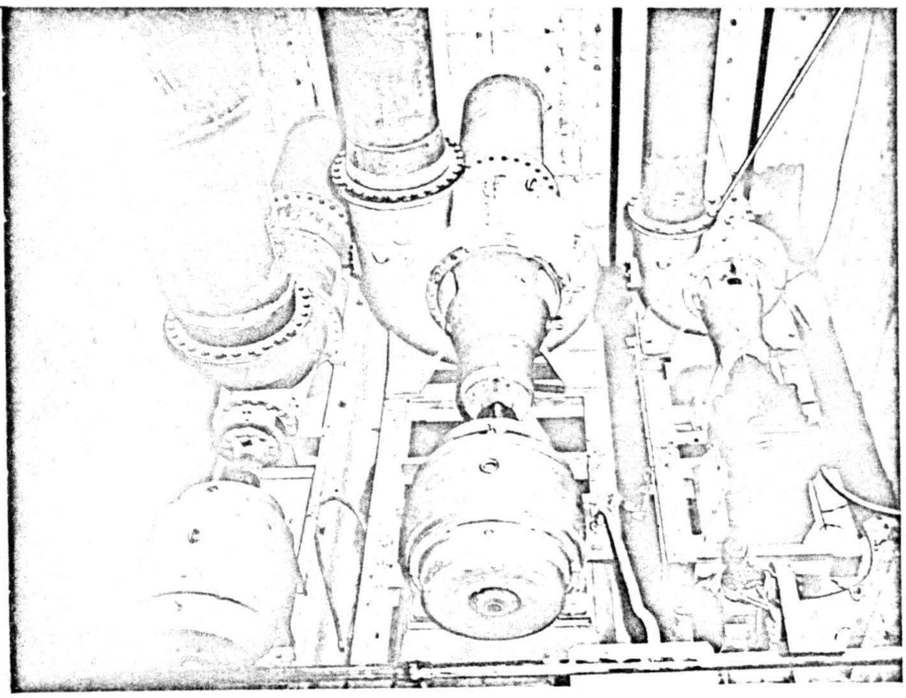

Fig. 11. Recirculating pump units installed in a chamber, 10 feet below the main floor and adjacent to the flume outfall sump.